A System for Autonomous Tracking and Following of Sharks with an Autonomous Underwater Vehicle

Related Works

By
Esfandiar Manii
Advisor: Dr. Christopher Clark
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Chapter 1

Introduction

In the past few decades underwater world has enticed scientists to explore and research in many areas, e.g. Biological sciences, Naval Engineering, Mechanical Engineering, etc. Most of these affairs directly require humans to engage and as a consequence there is an increase in human-work time and costs. Through entering the AUVs to the underwater world arena, efforts have been undertaken to reduce those costs and increase productivity in all aspects. AUVs concatenated to other fields to help scientists do crucial missions, e.g. piping, exploring, etc. One aspect of underwater AUVs that stands out is the study of fish species. Information acquired by AUVs has helped scientists to have a better perspective of what they have known.

Throughout the world, acoustic tracking systems have brought a huge capacity for the underwater research on several species of fish. In most of those studies fish is caught, tagged and then released. As soon as fish gets into the water, an acoustic transmitter starts sending signals in 360 degrees around the fish. The receiver device receives and interprets signals. Through this process, the bearing and distance to the fish can be estimated. Thereby, if the acoustic transmitter system could be integrated with an autonomous AUV, there would not be any need for human monitoring. Therefore, the main purpose of this thesis was to design an autonomous mobile shark tracking system for long term missions with

admissible accuracy and consistency. This chapter presents some of the current research in tracking sharks using underwater AUVs and answers why autonomous shark tracking is necessary.

1.1 Autonomous Underwater Vehicle (AUV)

Autonomous Underwater Vehicle (AUV), belonging to the group of unmanned vehicles, is a type of AUV that can operate without human aid. The main reason for designing such AUVs is to ease the research for scientists in hard or dangerous situations. AUV can operate missions that a human is able to perform. The first AUV was developed in the Applied Physic Laboratory at the University of Washington in 1957, by Stan Murph, Bob Francois and later improved by Terry Ewart. The "Special Purpose Underwater Research Vehicle", or SPURV, was used to study diffusion, acoustic transmission, and submarine wakes [19]. Currently, numerous operations are being done by AUVs. They range in size based on the operation(s) they might perform. AUVs are mostly used in the following areas: 1) Research and studies purposes, 2) Commercial Purposes, and 3) Military Purposes [32]. Research mostly focuses on localization and mapping of the underwater environment. The rate of mapped areas underwater is five percent [39]. AUVs can perform this operation more accurately than humans. However, AUVs encounter several problems including oceans currents and waves which may move AUVs to any unpredictable location. Water is roughly 1000 times denser than air. In this environment, electromagnetic signals cannot pass through water as easily as passing through air and therefore diminish much faster.

As a result, GPS signals can only be useful when the AUV is on the water surface or in shallow water. To localize itself, AUVs use their sensors for positioning purposes. To perform positioning, various experiments have been done through the years. These experiments include; Conventional Long Baseline (LBL), Short Baseline (SBL), or Ultra Short Baseline (USBL) systems which are now being offered as combined systems. The unique LBL (least squares adjustment of lines of positions) or USBL (phase correlation to generate wave vectors) solutions then have to be combined with external sensor data to provide the adjusted position [33], optical analysis, which consists of color, texture, shape and dynamic properties of the environment. Here, the dynamic properties from image sequences can be used for target tracking by Autonomous Underwater Vehicles (AUVs) is studied [34, 35], Inertial Navigation system (INS) which improves autonomous underwater vehicle navigation for undersea explorations [36]. Also the strategic and tactical applications for autonomous submersibles place great demand on the platforms' passive sonar signal and data processing abilities. It is necessary to overcome the limited acoustic aperture and lack of human supervision by exploiting synergism between front-end signal processing functions and back-end data fusion algorithms [37]. Other types of experiments include object tracking in the underwater environment which will be discussed in the next section.

1.2 Current Research in Underwater Tracking

Underwater tracking operations are widely being done in underwater research. In most cases, the main desired goal is to study particular objects by manual-tracking instruments on-board, at piers, or by satellites. To track objects underwater, two methods are widely used: 1) Acoustic tracking, and 2) GPS tracking. Acoustic tracking systems are one of the most popular research tools based on other studies [9, 10, 11, 12]. These systems let researchers track objects with less labor intensive activities [9], but still require human operations to simultaneously track signals from the tags [14]. In the recent years, studies have benefited from several advances in acoustic transmission systems. These studies have mainly focused on how to design arrays of hydrophones to detect underwater habitats [20, 21, 22, 23, 24] as well as gaining data from the environment and the animal using triangulations [25, 26, 27]. Most of the developments were based on research conducted using fixed hydrophones in the experimental areas. Furthermore, those technologies led to new era of mobile acoustic tracking where fixed hydrophones were placed on a boat or ship to track animals [28]. Often acquired results from these studies are not accurate enough due to human errors; thereby, a new technology would be needed to improve the efficiency and reduce the error. On the other side, GPS tracking systems works different than acoustic tracking systems. Tracking systems were originally based on GPS technology initiated in 1990s to acquire the regions in which terrestrial and Volant animals live [30, 31]. Utilizing GPS technology has some advantages over other methods due to: 1) High spatial accuracy and temporal resolutions, 2) Capacity to collect large databases about environments, 3) Ability to localize without human aid, and

4) Ability to locating any individuals. The only disadvantage is that GPS Technology requires animals to swim close to the water surface. When an animal descends to deep, tracking operations fail due to signal loss [29]. To localize and track sharks several methods can be manipulated: e.g. 1) Stationary acoustic receivers are spread in a specific area to track sharks at any time, and 2) Boats can patrol the sea to find a tagged shark and to follow that shark's movements. These solutions lack data logging accuracy and in experiments some sharks have been lost for long periods of time, the consequences have been an accretion in costs and human work-load.

Currently, autonomous underwater vehicles (AUVs) are well known for their high efficiency and accuracy this is a good reason to combine AUVs with other technologies to benefit research. [16] Addresses the reason to operate AUVs for underwater explorations and research. AUVs have the potential to revolutionize our access to the oceans to address critical problems facing the marine community. Efforts to design and implement control systems and algorithms for tracking objects in dynamic environments have been done before. These methods suggest a probabilistic data association filtering to track the moving objects with mobile AUVs, [1, 2, 15], that can be extended to the underwater environment. Tracking objects in underwater environments using acoustic systems has been known as a good way of localization [3]. Some studies have been done to track Sperm Whales with AUVs by using two arrays of hydrophones to auscultate the signals from them for tracking and localization [4, 5]. Also for localization of underwater targets, methods have been developed to reduce the imperfections in

vehicle control using Sonars [6]. Since imperfections can be solved, studies have been done to increase the range of acoustic signals to be used by an AUV resulted in range enhancement of acoustic devices [7]. Numerous studies also have been done to record the sounds of the underwater mammals in order to inspect their lives [8]. None of the previous studies have utilized an AUV integrated with acoustic transmission system. Also, shark tracking operations have never been performed by AUVs equipped with acoustic devices. The main difference between this thesis and previous research is to use an acoustic system in non-stationary states attached to an AUV to track any type of fish species underwater. The AUV AUV in this paper is equipped with an acoustic transmission system and stereo-typed hydrophones. Also, a particle filter algorithm (PF) has been used to enable the real time tracking for localization.

1.3 Why Sharks?

Based on the information provided by ISAF "International Shark Attack File" [17], every year sharks attack fatally and non-fatally. Although sharks threaten human life, sharks must also be protected. White Sharks are threatened with extinction. The number of White Sharks has been reduced in the past years and biologists are worried about their future. If the path of the migration of sharks and their behavior become clear to scientists, dangerous locations close to the shore would be recognized and the number of attacks close to beaches could be reduced. To perform this important task, scientists need to understand the shark's behavior in order to answer complicated questions including: Which habitats do sharks

prefer? What is the size of their home ranges? Do White Sharks show fidelity to particular sites, such as hunting grounds, and if so for how long? How far do White Sharks travel? Do White Sharks have regular migrations, and if so what are the sizes and routes of these migrations? What are the relationships between great White Sharks that live in different parts of the world? Are the movements of White Sharks driven by environmental factors? If so, which are the most important of them? Therefore, autonomous shark tracking can be useful for two purposes: 1) Tracking for attack prevention, and 2) Extinction prevention. AUVs track sharks to study their behaviors.
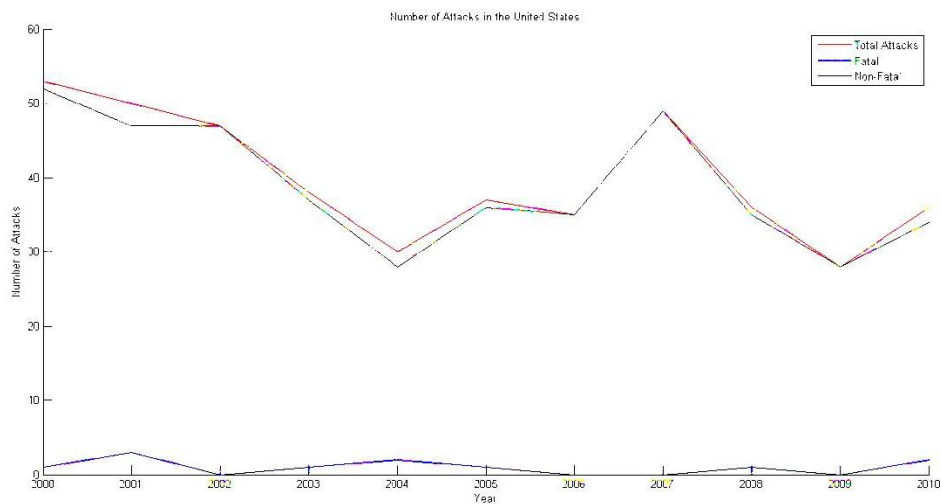

Figure 1.1: Number of shark attacks in the United State.

1.4 Current Methods of Shark Tracking

To locate a shark, the easiest way would to take advantage of its nature. One of the main reasons sharks are such effective predators is their keenly

attuned senses. Initially, scientists thought of sharks as giant swimming noses. When researchers plugged the nasal openings in captive sharks, the sharks had trouble locating their prey. This seemed to demonstrate that the shark's other senses were not as developed as the sense of smell. Further research demonstrated that sharks actually have several acute senses, but that they depend on all of them working together. When you take one away, it significantly hinders the shark's hunting ability [18]. Therefore by providing an enough amount of blood in the environment, sharks can be easily distracted and lured to the bait. Besides this basic method to track a shark, other methods are being used widely in research such as satellite and acoustic tracking. In the first method a near-real time tag is attached to a shark. When the shark swims in shallow water or gets close to the water surface, the tag sends the signal to the satellite and by getting those signals the shark can be located. The other method is acoustic tracking which an acoustic transmitter is attached to a shark after leaving the shark; scientists are required to follow the signals from the tag by acoustic transmitter receivers.

1.5. Objectives of Shark Tracking Research

Specific objectives for the overall project were defined as:

Shark Locomotion Characterization – This part of the research focuses on modeling the different behavior modes of a shark including, resting, foraging, etc., as well as modeling the transitions between these modes. In every mode, shark locomotion kinematics will be modeled as well as associated model certainty.

AUV Marine Tracking Technology – To track a shark, AUV must incorporate the acoustic transmission system to localize the shark. This operation needs a well-defined strategy for the predefined situations in which the AUV would encounter while tracking the shark. Accurate planning is a complex issue to solve when the shark goes into regions which reduces the reception of the acoustic transmitter. This planning should also consider speed, distance, and the depth of the AUV relative to the shark to be at low value.

Shark Behavior Characterization – Tracking sharks helps us to answer vague questions about these creatures. AUV tracking helps scientists to track sharks for a long period without any human aid.

1.6. Objectives of the current research

This thesis only focuses on "AUV Marine Tracking Technology" which its purpose is to design an autonomous mobile shark tracking system. All components of the system will be discussed in the next chapter. The validation and experiments results are covered in the later chapters.

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